

# JKJ Lattice

20<sup>th</sup> ICFA Advanced Beam Dynamics Workshop  
on High Intensity and High Brightness Hadron Beams  
on  
April 9, 2002  
at  
Fermilab, IL, U.S.A.

presented by

Kenta Shigaki

(Japan Atomic Energy Research Institute)

for the

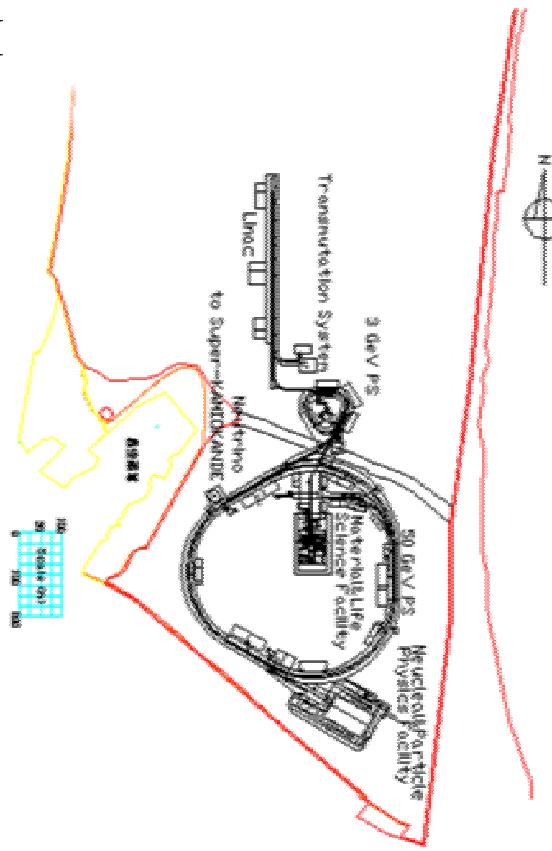
JKJ RCS/MR Lattice Team

# Presentation Outline

- JKJ Accelerator Complex
- 3 GeV Rapid-Cycling Synchrotron (RCS)
  - design concepts
  - characteristic parameters
  - ring details
    - layout, lattice functions, physical aperture, operation point, tunability, dynamic aperture, COD correction, space-charge effect, ...
    - injection, collimation, extraction
- 50 GeV Synchrotron (MR)
  - design concepts
  - characteristic parameters
  - lattice functions
- Status and Outlook

# JKJ Accelerator Complex

- JAERI-KEK joint project
  - ref. Y.Mori, Monday afternoon*
  - unification of JHF at KEK and NSP at JAERI
  - high intensity proton accelerator facility
  - located in Tokai site of JAERI
  - nickname in public contest
- accelerator complex
  - 400 MeV linac
    - ref. M.Ikegami, WG II, Tuesday afternoon*
    - nuclear transmutation system
  - 3 GeV rapid-cycling synchrotron (RCS)
    - ref. F.Noda, WG I, Tuesday afternoon*
    - spallation neutron and muon sources
  - 50 GeV synchrotron (MR)
    - particle and nuclear physics beamlines



# 3 GeV Rapid-Cycling Synchrotron (RCS)

- 400 MeV protons from Linac
- 3 GeV 1MW protons to neutron and muon facilities
  - materials and life sciences
  - muon physics
- 3 GeV protons to MR

## RCS Lattice Team Core Members

- F.Noda, K.Shigaki, K.Yamamoto (JAERI)
- S.Machida (KEK)
- Y.Ishi (Melco)

# RCS Design Concepts

- 1 MW output beam power
  - 3 GeV,  $8.3 \times 10^{13}$  ppp, 25 Hz
- beam loss control and localization
  - transverse and longitudinal beam collimation
- large acceptance to suppress incoherent tune shift
  - $486 \pi$  mm mrad for  $324 \pi$  mm mrad beam
- three-fold + mirror symmetry
- high transition  $\gamma$  with missing bends
- achromatic arcs and long dispersion-free insertions
  - injection + beam collimation
  - RF acceleration
  - fast extraction

# RCS Characteristic Parameters (1)

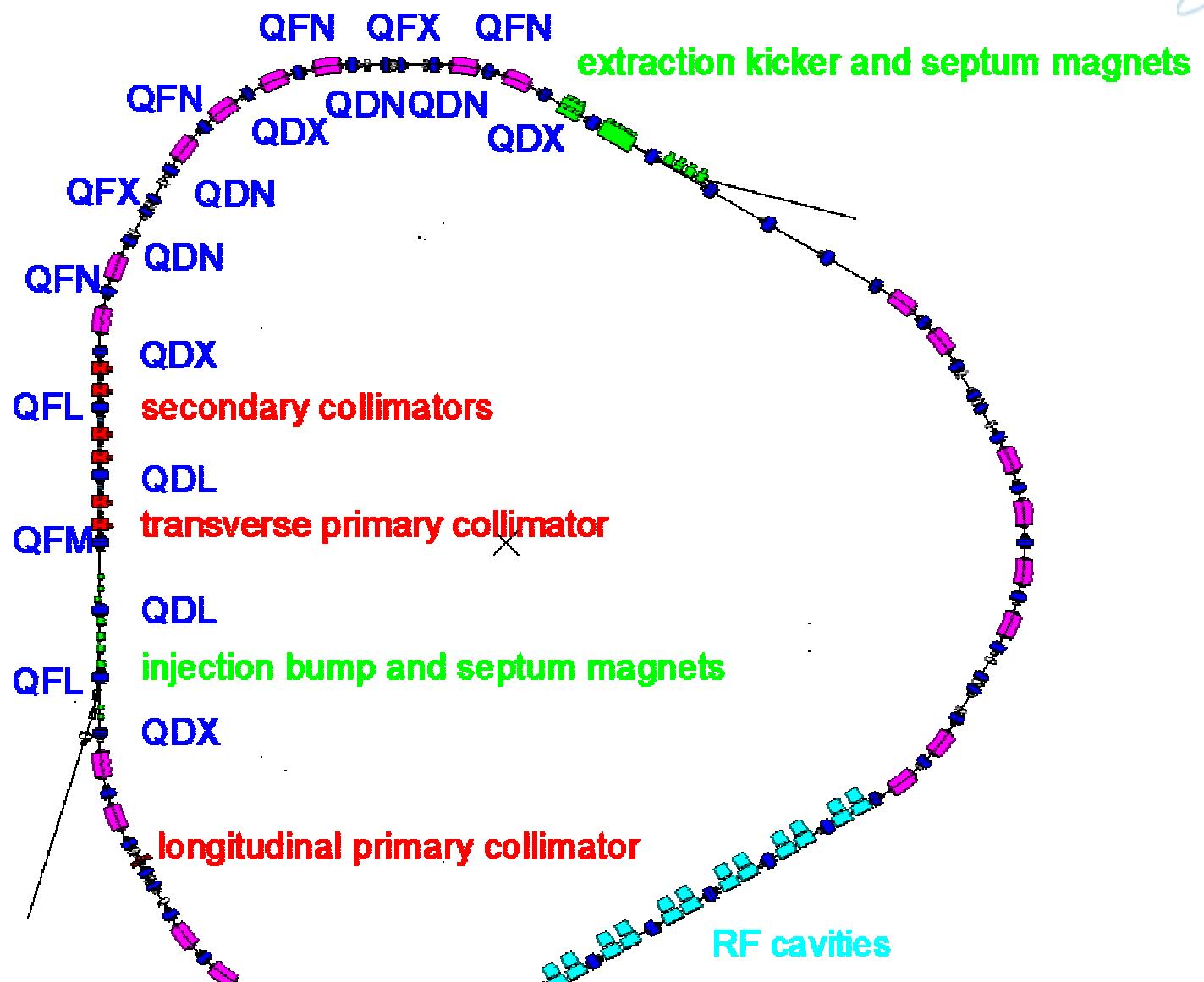
- beam parameters
  - injection energy 400 MeV
  - extraction energy 3.0 GeV
  - repetition rate 25 Hz
  - harmonics 2
  - output power 1 MW
- lattice parameters
  - circumference 348.333 m
  - cell structure (6 FODO arc + 3 FODO insertion)  $\times$  3
  - nominal tune (6.72, 6.35)
  - natural chromaticity (- 8.5, - 8.8)
  - transition  $\gamma$  9.14
  - momentum compaction 0.012

# RCS Characteristic Parameters (2)

- transverse emittance and acceptance
  - injection beam emittance  $4 \pi \text{ mm mrad}$
  - painting emittance  $216 \pi \text{ mm mrad}$
  - collimator acceptance  $324 \pi \text{ mm mrad}$
  - physical acceptance  $486 \pi \text{ mm mrad}$
  - beam core at extraction  $81 \pi \text{ mm mrad}$
  - extraction acceptance  $324 \pi \text{ mm mrad}$
- longitudinal emittance and momentum spread
  - beam emittance  $3.5 \text{ eVs at injection}$
  - injection beam momentum spread  $5.0 \text{ eVs at extraction}$
  - ring acceptance  $\pm 0.1 \%$
  - $\pm 1.0 \%$  for  $486 \pi \text{ mm mrad}$
- incoherent tune shift
  - with bunching factor = 0.41  $(-0.16, -0.16)$  at injection

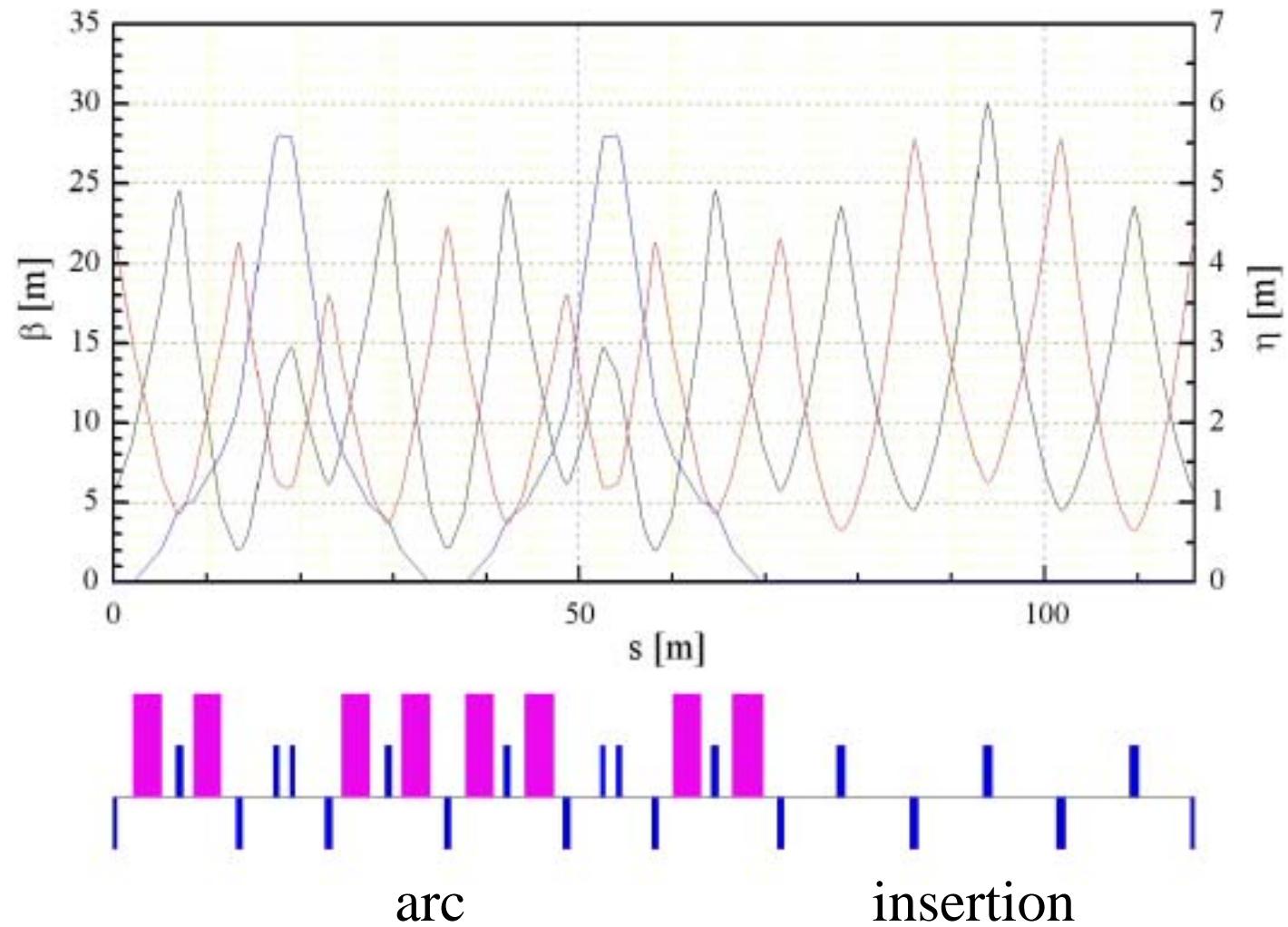
# RCS Layout and Lattice Functions

- FODO cells
  - small field gradient required for quadrupole magnets
    - large aperture and short length
  - large phase advance per cell
    - effective arrangement of secondary beam collimators
- dispersion peaks at missing bends
  - longitudinal beam collimation
  - chromaticity correction
- long dispersion-free insertions
  - transverse beam collimation
  - painting injection
  - RF acceleration





—  $\beta_x$  —  $\beta_y$  —  $\eta_x$

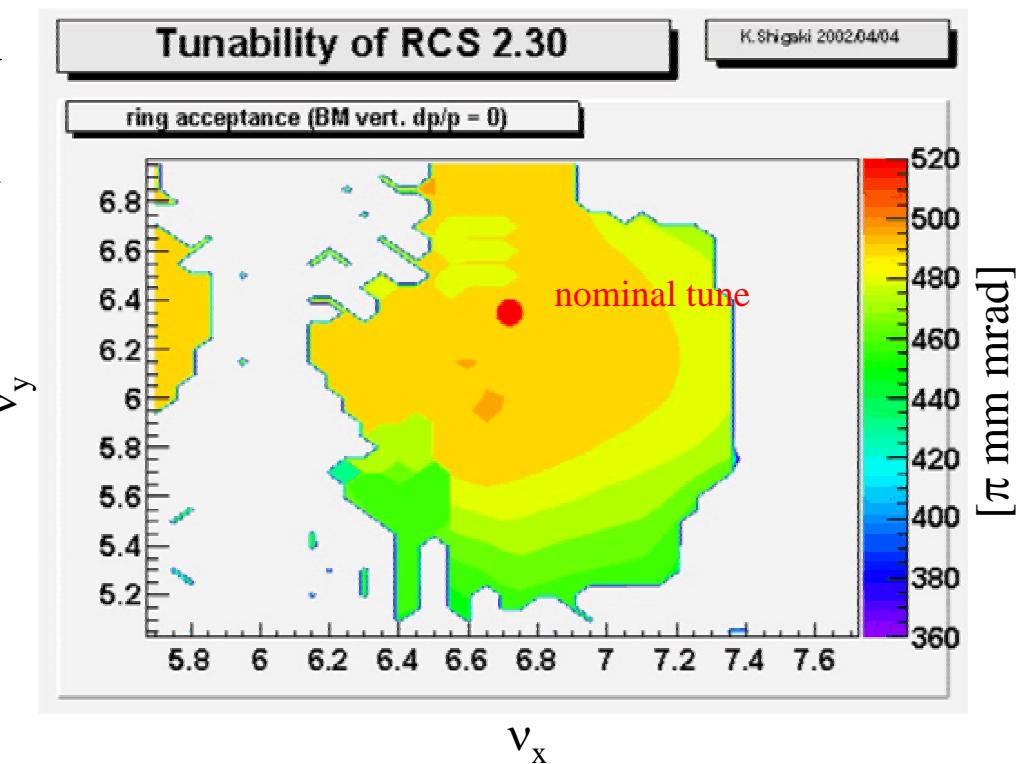


# RCS Physical Aperture

- magnet aperture to cover design acceptance
  - $486 \pi$  mm mrad,  $\pm 1.0\%$  momentum spread
  - vacuum duct with square or oval cross section at bending magnets
    - 210 mm full gap height, 240 mm wide good field region
  - large aperture quadrupole and sextupole magnets
    - 205 mm max. bore radius
- still a limiting factor for tunability

# RCS Operation Point and Tunability

- nominal tune at  $(\nu_x, \nu_y) = (6.72, 6.35)$ 
  - to avoid structure resonance
  - small  $\beta$  modulation with bump orbit
- tunability
  - to cover tune shift and excursion
  - possibility of alternate operation points

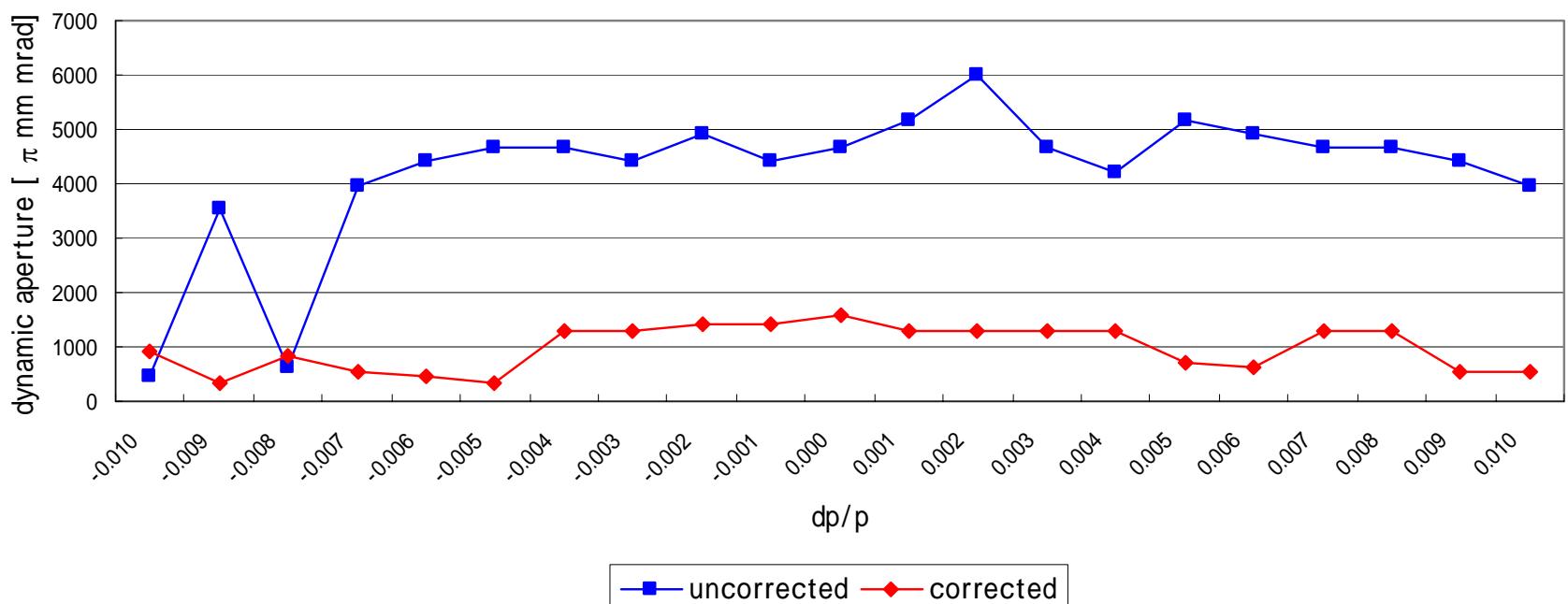


# RCS Dynamic Aperture

- designed to cover physical aperture
  - effects of fringing field studied in detail

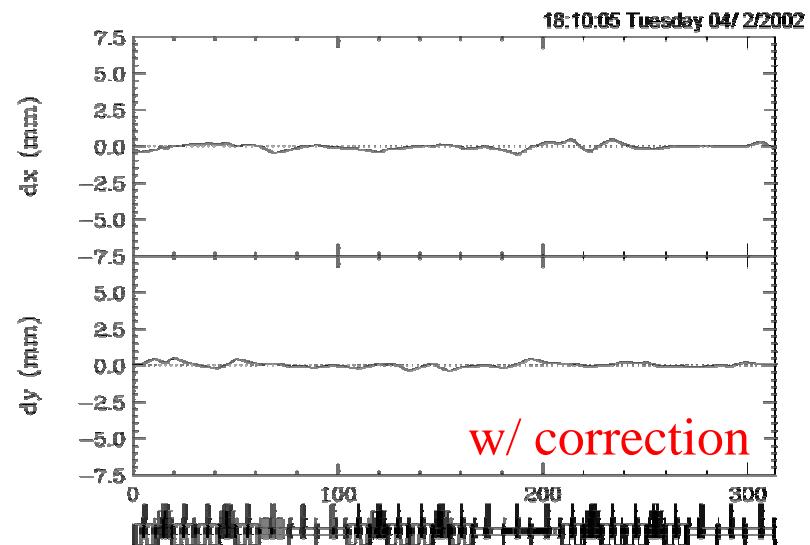
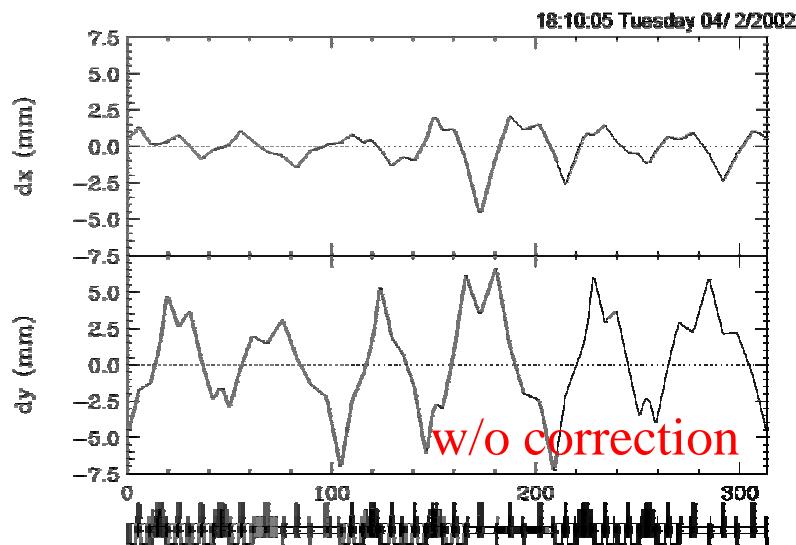
*ref. A.Molodojentsev, next talk*

dynamic aperture w/ and w/o chromaticity correction



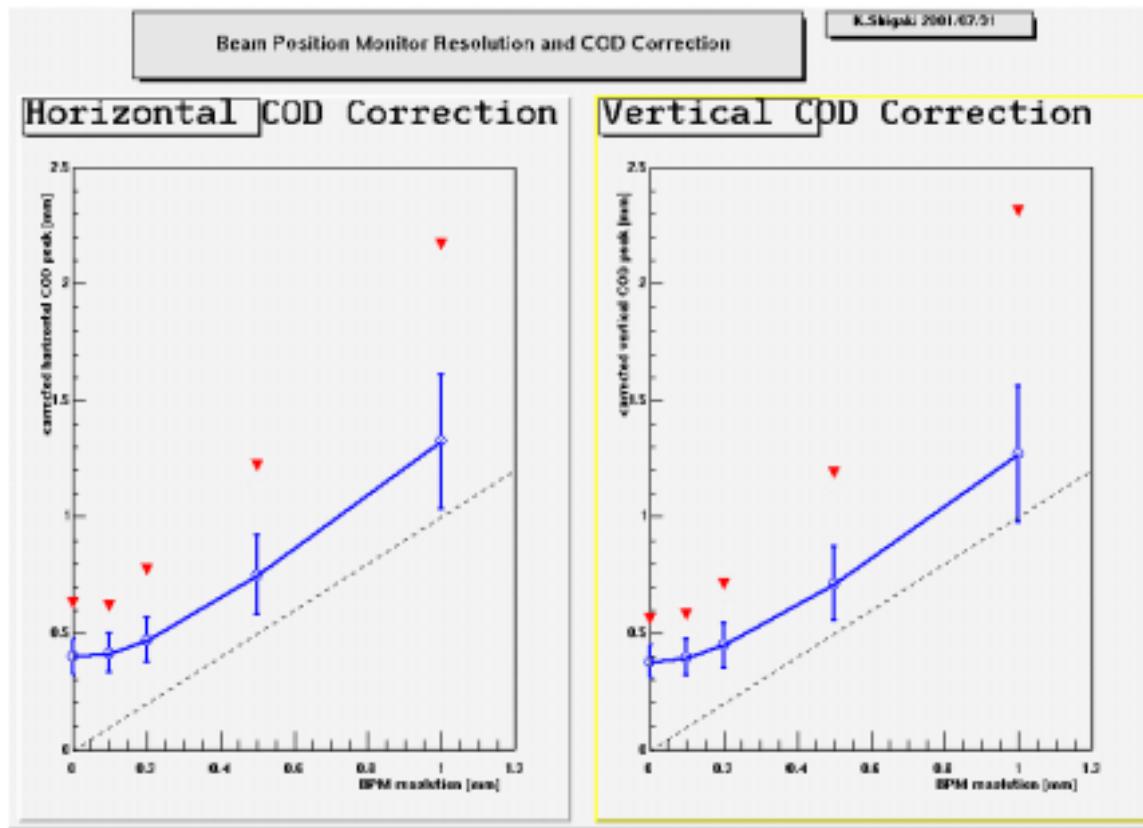
# RCS COD Correction (1)

- assumed error sources
  - magnet displacement 0.25 mm r.m.s.
  - magnet rotation 0.5 mrad r.m.s.
  - field strength error  $5 \times 10^{-4}$  r.m.s.
- closed-orbit distortion
  - up to  $\sim 10$  mm without correction
  - correctable within  $\pm 1$  mm



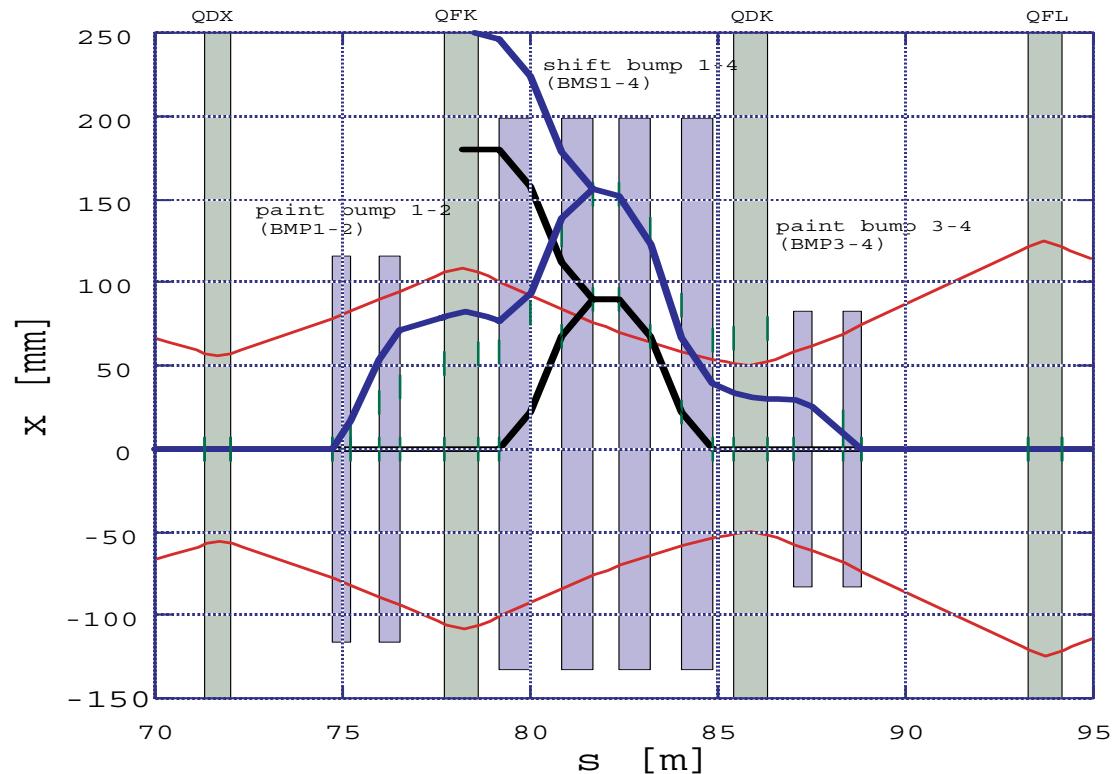
# RCS COD Correction (2)

- beam position monitors and correction dipole magnets
  - basically paired in each half cell
  - monitor resolution  $\sim 0.2$  mm r.m.s. for residual COD  $< \pm 1$  mm



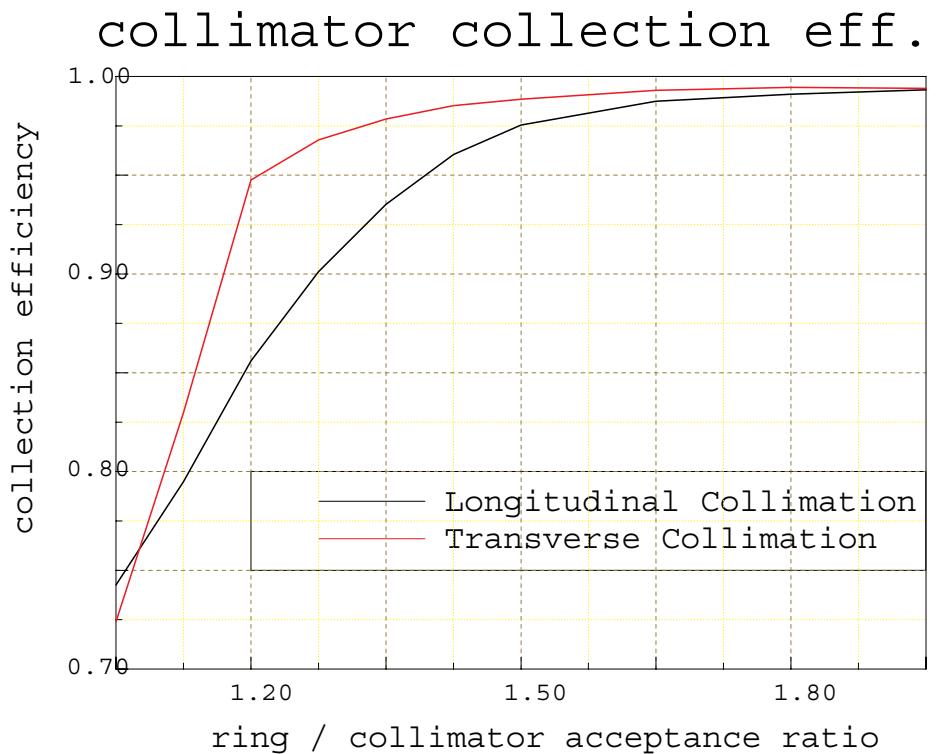
# RCS Injection

- multiple injection schemes
  - center / off-center injection for commissioning
  - painting injection for optimum operation
    - transverse painting scheme study in progress



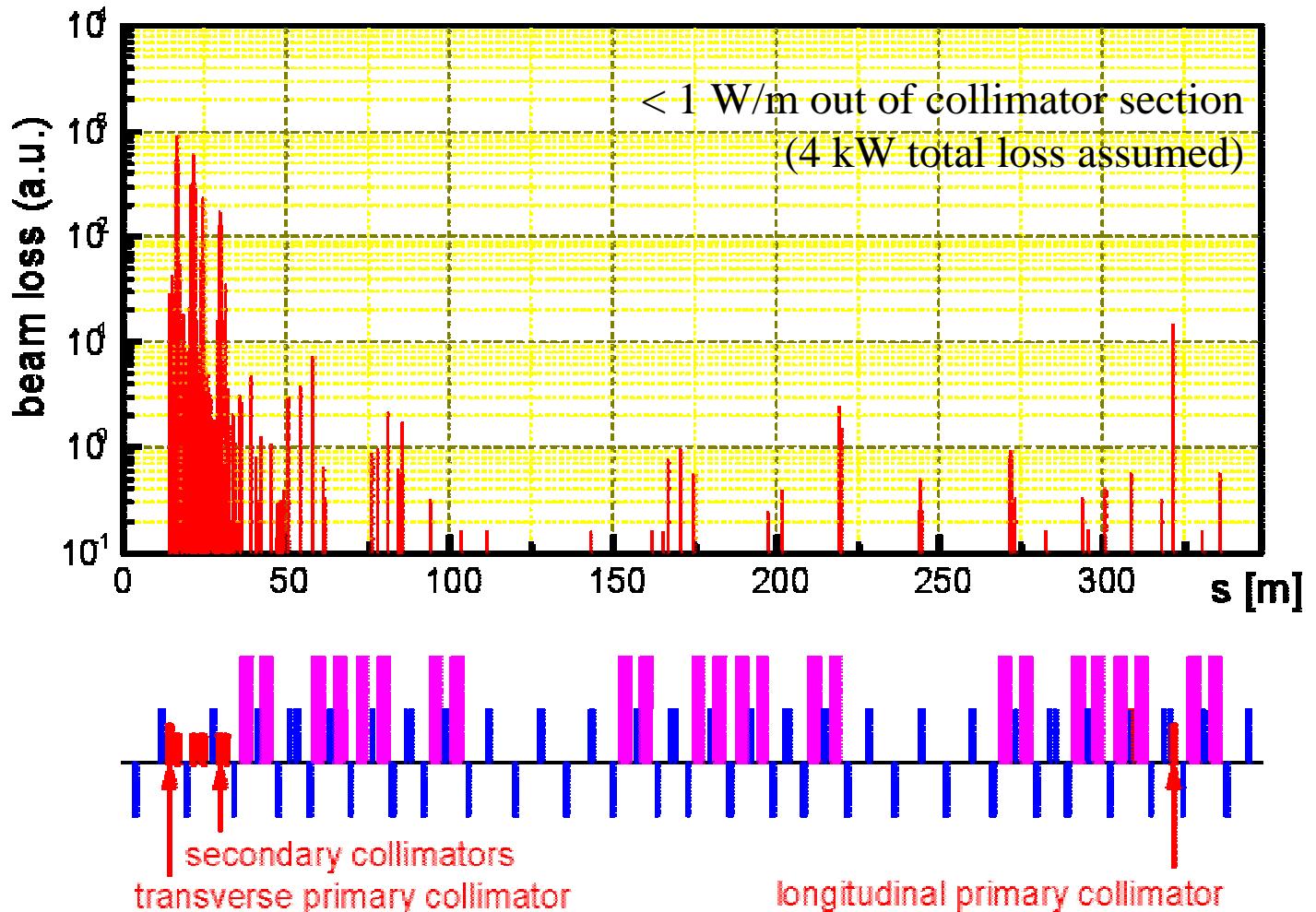
# RCS Beam Collimation (1)

- strategies
  - beam loss control and localization
    - transverse and longitudinal collimation
    - primary (scattering) and secondary (collection) collimators
  - variable collimator acceptance
  - ring / collimator acceptance ratio = 1.5 for ~ 98 % collection efficiency



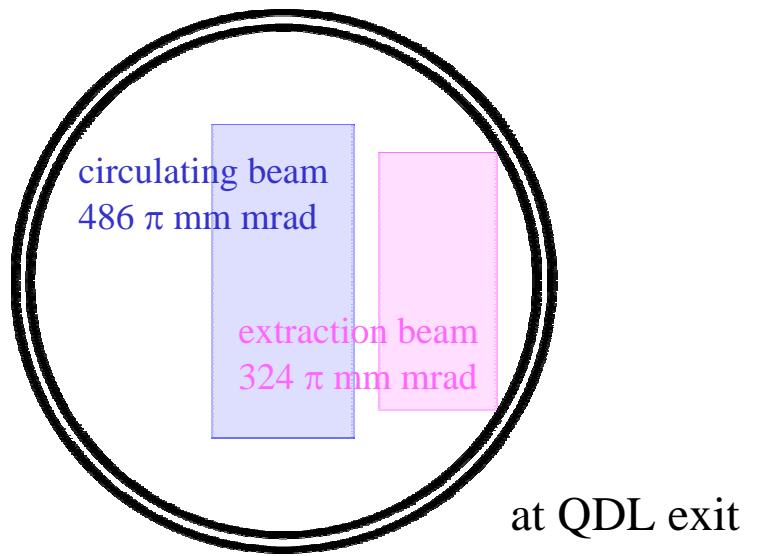
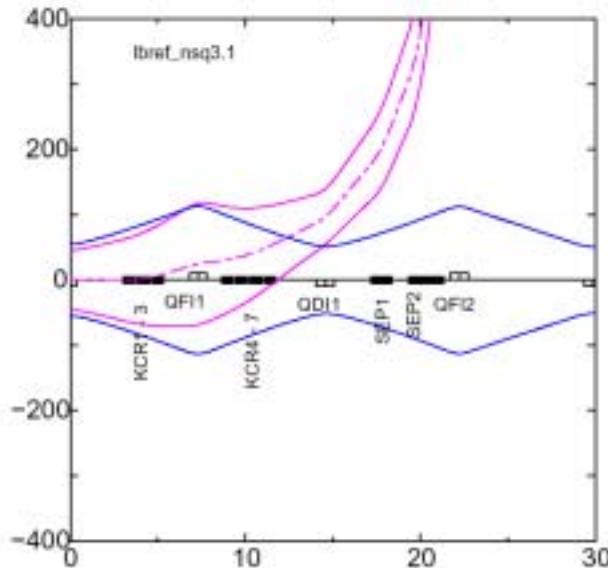
# RCS Beam Collimation (2)

- beam loss localization



# RCS Extraction

- designed to extract  $324 \pi \text{ mm mrad}$ 
  - halo up to collimator acceptance
  - core emittance at extraction =  $81 \pi$  ( $54 \pi$  for MR) mm mrad
- 7 kicker magnets + 4 septum magnets
  - large aperture kickers
    - 180 mm max. full gap height



# 50 GeV Synchrotron (MR)

- 3 GeV protons from RCS
- 50 GeV 0.75 MW protons to physics facilities
  - fast extraction
    - neutrino beamline for Super-Kamiokande  
*ref. WG III, Wednesday afternoon*
  - slow extraction
    - primary and secondary beamlines

## MR Lattice Team Core Members

- S.Machida, A.Molodojentsev, Y.Mori (KEK)
- Y.Ishi (Melco)

# MR Design Concepts

- 0.75 MW output beam power
  - 50 GeV,  $3.3 \times 10^{14}$  ppp, 0.3 Hz
- fast and slow extractions
- three-fold symmetry
- imaginary transition  $\gamma$  with missing bends
- achromatic arcs and long dispersion-free insertions
  - injection + abort + beam collimation
  - RF acceleration + fast extraction
  - slow extraction

# MR Characteristic Parameters (1)

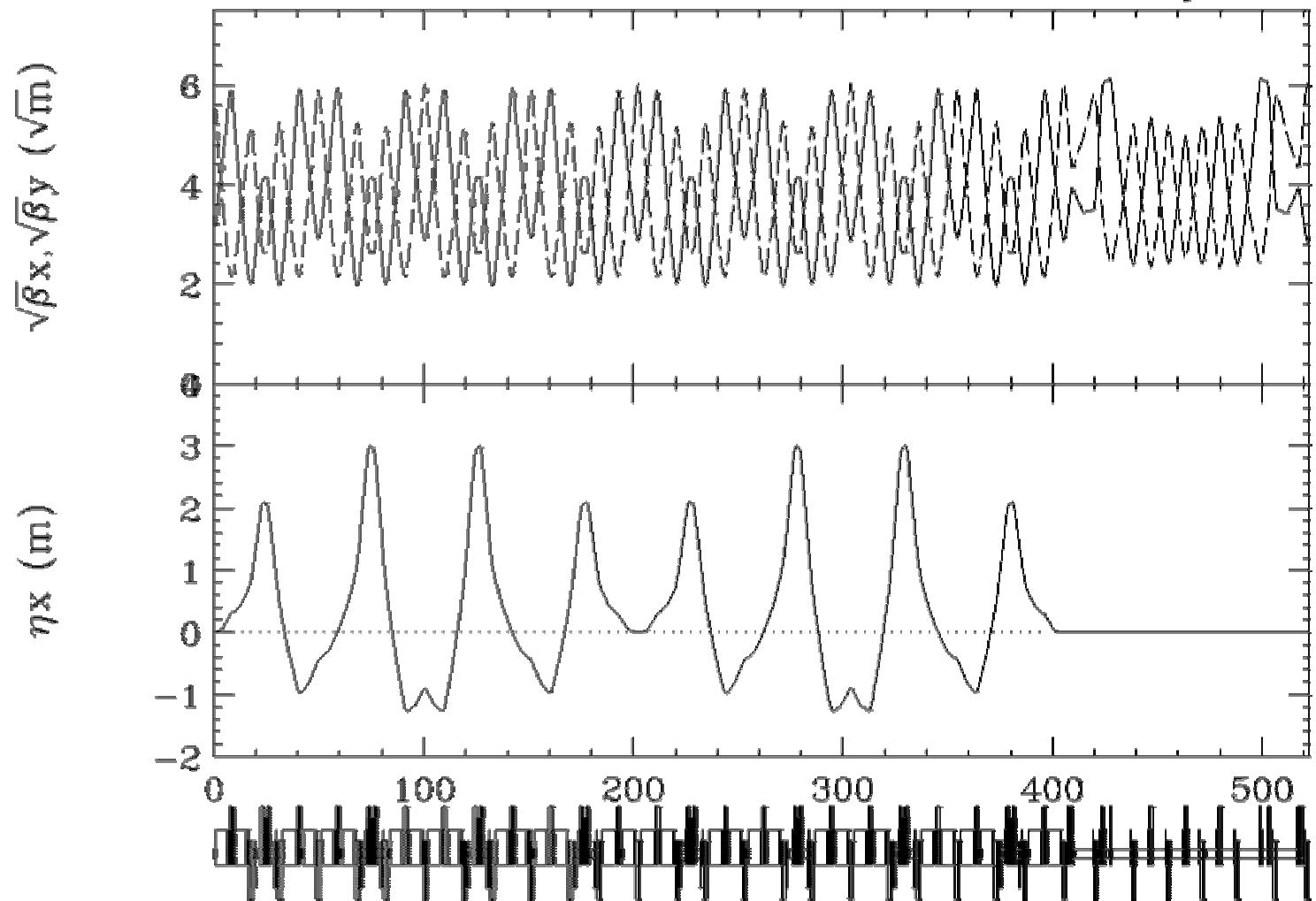
- beam parameters
  - injection energy 3.0 GeV
  - extraction energy 50 GeV
  - repetition rate 0.3 Hz
  - harmonics 9
  - output power 0.75 MW
- lattice parameters
  - circumference 1567.5 m
  - cell structure (24 FODO arc + 3 FODO insertion + 4 matching cells)  $\times$  3  
(22.25, 22.23)
  - nominal tune
  - bare chromaticity
  - transition  $\gamma$  imaginary
  - momentum compaction

# MR Characteristic Parameters (2)

- transverse emittance and acceptance
  - injection beam emittance                            $54 \pi \text{ mm mrad}$
  - physical acceptance                                $81 \pi \text{ mm mrad}$
  - beam core at extraction                            $10 \pi \text{ mm mrad}$  at 30 GeV
  - extraction acceptance                               $6.1 \pi \text{ mm mrad}$  at 50 GeV
  - extraction acceptance                               $> 10 \pi \text{ mm mrad}$
- longitudinal emittance and momentum spread
  - beam emittance                                    $10.75 \text{ eVs}$  at injection
  - injection beam momentum spread                $10.75 \text{ eVs}$  at extraction
  - injection beam momentum spread                $\pm 0.67 \%$  (simulated)
  - injection beam momentum spread                $\pm 1.0 \%$  max.
- incoherent tune shift
  - with bunching factor = 0.336                      $(-0.062, -0.166)$  at injection

# MR Lattice Functions

14:23:28 Thursday 04/4/2002



# Status and Outlook

- RCS/MR lattice design basically fixed
  - most key issues examined and cleared
- further performance studies ongoing, *e.g.*
  - space-charge effect
    - ref.* S.Machida, Y.Shimosaki, session E, Wednesday morning
  - RCS injection painting
- challenging hardware R&D in progress
  - ref.* M.Tomizawa, session B, Tuesday morning
  - F.Noda *et al.*, WG I, Tuesday afternoon
  - feedback to lattice design as needed
- construction starting in 2002
- RCS first beam in October, 2006; MR in April, 2007
  - commissioning scenarios
  - interface between simulation and operation